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August 2, 2011

APS Condensed Matter Shock Conference
Chicago, IL, United States
June 26, 2011 through July 1, 2011

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SIMULATION OF THE REFLECTED BLAST WAVE FROM A C-4 CHARGE

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The reflection of a blast wave from a C4 charge detonated above a planar surface is simulated with our ALE3D code. We used a finely-resolved, fixed Eulerian 2-D mesh (167 μm per cell) to capture the detonation of the charge, the blast wave propagation in nitrogen, and its reflection from the surface. The thermodynamic properties of the detonation products and nitrogen were specified by the Cheetah code. A programmed-burn model was used to detonate the charge at a rate based on measured detonation velocities. Computed pressure histories are compared with pressures measured by Kistler 603B piezoelectric gauges at 8 ranges (GR = 0, 2, 4, 8, 10, and 12 inches) along the reflecting surface. Computed and measured waveforms and positive-phase impulses were similar, except at close-in ranges (GR < 2 inches), which were dominated by jetting effects.

Keywords: Air blast, turbulence, hydrodynamics, detonation

PACS: 47.27.E-, 47.10.Fg, 47.20.Ma

INTRODUCTION

We study the reflected blast wave environments created by the detonation of C-4 charges in nitrogen. Experiments were performed in our barometric calorimeter [1] and numerical simulations of the experiments were performed with our Arbitrary-Lagrange-Eulerian (ALE3D) hydrodynamics code [2]. The calorimeter chamber was a right circular cylinder with 5 cm thick steel walls and interior dimensions of $D = H = 86$ cm, and a volume of 506 liters.

Numerical simulations of the experiments were performed with our Arbitrary-Lagrange-Eulerian (ALE3D) hydrodynamics code. We used a finely-resolved, fixed-Eulerian 2-D mesh (60 zones/cm) to capture the detonation of the charge, the blast wave propagation in nitrogen, and the reflection of the blast wave from the chamber lid and walls. The thermodynamic properties of the detonation products gases and nitrogen were specified by the Cheetah code [3], used as an in-line equation of state (EOS) routine. We used a

programmed-burn model to detonate the charge at a rate based on the experimental detonation velocity of 8.2 km/s. The simulation was run to 0.4 ms. Peak temperatures of more than 6,500 K were observed in the reflected-wave region. Computed pressure histories were compared to the measured waveforms. Overshoots were observed in the computed waveform at $r = 0$ due to numerical jetting along the axis. At other ground ranges, computed pressure waveforms and positive-phase impulses were qualitatively similar to the measurements. Under such conditions, the JWL and gamma-law EOS are inappropriate; one needs a complete EOS to correctly specify all thermodynamic properties of the detonation products and nitrogen; in-line Cheetah serves this general purpose

EXPERIMENTAL PROCEDURE

The principal diagnostic consisted of eight Kistler 603B piezo-electric pressure gauges located

on the chamber lid at: at $r = 0$ and at $r = 5, 10, 15, 20, 25$ and 30 cm. Signals were recorded on a Yokogawa DL-750 digital storage system at 10 mega-samples per second and 12-bit resolution

BLAST WAVE MODEL

Initial Conditions

We assumed 2-D symmetry, so the computational domain ($0 < r < 43$ cm by $-2 < z < 43$ cm) was only one quarter of the chamber volume. A uniform finely resolved (60 cells/cm) fixed Eulerian mesh was used. We do not include the effects of thermal transport, nor the effects of afterburning of the reaction products with nitrogen.

Equation of State (EOS)

As a baseline, we used the Cheetah code [3] as subroutine to supply the thermodynamic properties of the C-4 detonation products gases, which are needed to define the equations of state (EOS) in the ALE code simulations. Nitrogen was also modeled with an equilibrium Cheetah model that takes into account molecular dissociation of nitrogen, but not ionization.

RESULTS

Flow Visualization

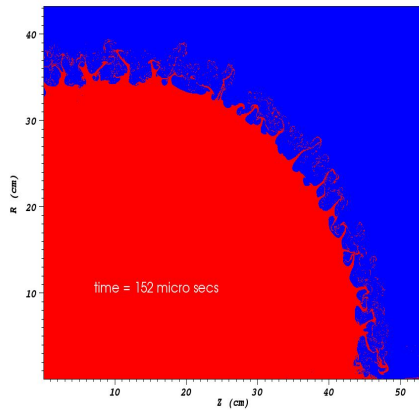


Figure 1. Material composition field at a time $152 \mu\text{s}$. The red region designates regions of detonation products while the blue regions of designates nitrogen.

A cross-section of the material composition field at time $152 \mu\text{s}$ after the initiation of detonation is shown in Fig 1. The detonation products-air interface is unstable (as pointed out by Anisimov and Zel'dovich [4] and has developed Richtmyer-Meshkov structures. Figure 2 depicts the corresponding temperature field at time $152 \mu\text{s}$. The interface region has evolved into a spherical mixing layer shell, bounded by the main shock and the inner (imploding) shock. The blast wave is starting to be reflected from the surface.

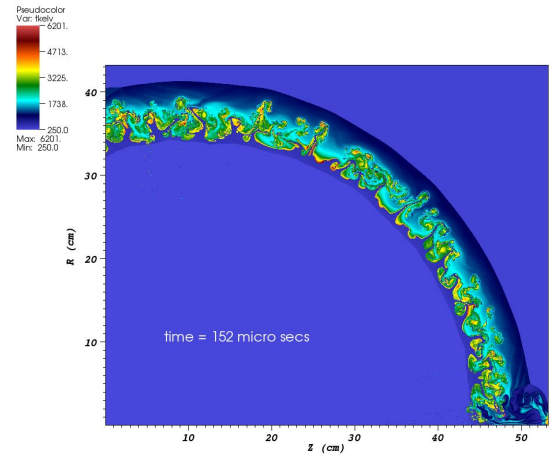


Figure 2. Temperature field at $152 \mu\text{s}$. The peak temperature is near 6000K .

Free Air Curve

The incident shock over-pressure was sampled from the calculation as the blast wave expanded. The results are shown as the free-air curve of shock over-pressure versus scaled radius: R ($\text{cm/g}^{1/3}$) in Fig .3. The curve was fit with the inverse power law function:

$$\Delta p(\text{atm}) = -4.7 + 713 / R^{1.66} \quad (1)$$

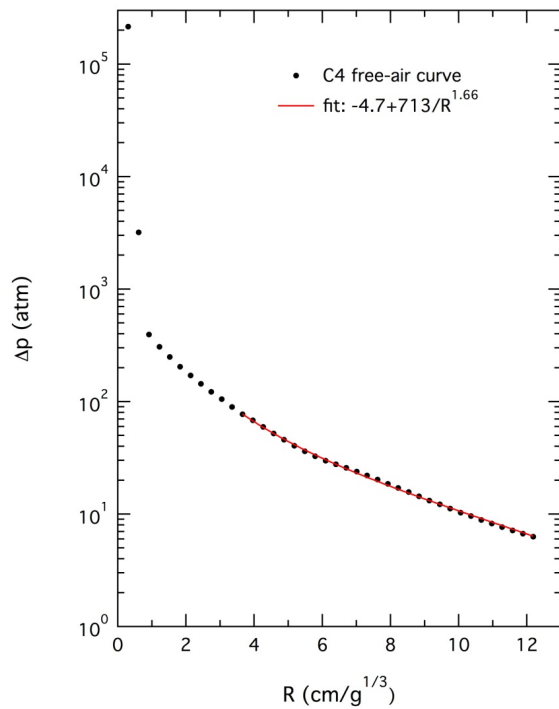


Figure 3. Free-air curve for C-4 (from 2-D ALE simulation along 45 deg. diagonal).

This gives an incident shock over-pressure of 13 bars at ground zero ($z = 43$ cm, $r = 0$); upon reflection, ground zero will experience a peak pressure of 40 bars.

Waveforms

The pressure histories from the calculation were sampled at the seven gauge locations on the wall ($GR = 0, 5, 10, \dots, 30$ cm), and stored. Some of these computed waveforms are compared with the measured pressure histories in Figs. 4 and 5. ALE results are shown as blue curves, while the experimental results shown as black.

Fig. 4 shows the comparison at a ground range ($GR = 5.0$ cm) at 5.0 cm. The first peak is somewhat high and all of the structure is not captured, while the noise comes from shock reflections off the turbulent mixing structures on the fireball interface (see Fig. 2), and is qualitatively realistic—although more pronounced than in the experiments.

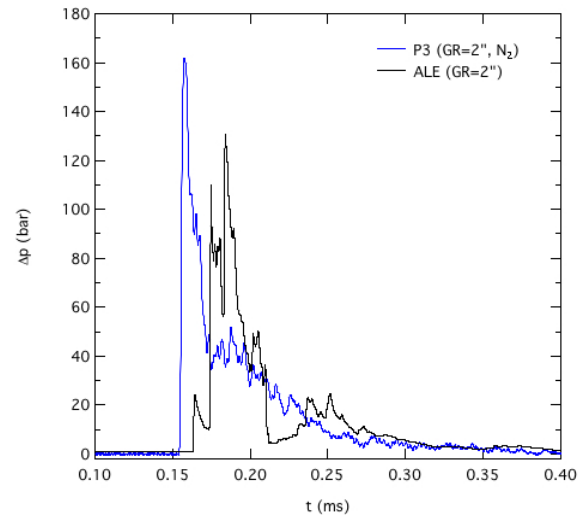


Figure 4. Computed pressure history (blue curve) vs. measured waveforms ($GR = 5$ cm).

Fig. 5 shows a comparison at a ground range of 30 cm ($GR = 30$ cm). At this ground range the time structure is less complicated at the calculations reproduce the general structure. As we will see below, the calculated impulses agree very well with experiments.

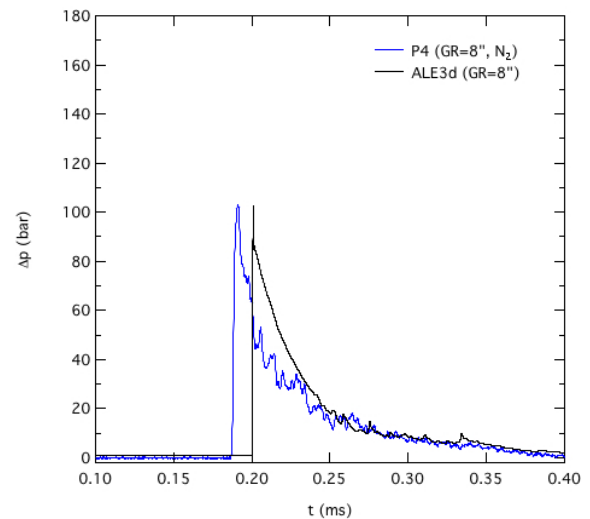


Figure 5. Computed pressure history (blue curve) vs. measured waveforms ($GR = 30$ cm).

Positive-Phase Impulse

The waveforms for the range of the experiment have been integrated to evaluate the positive phase impulse, I_+ , according to:

$$I_+(GR) = \int_0^{\tau_+} \Delta p(GR, t') dt' \quad (2)$$

where τ_+ denotes the positive phase of the primary (first) blast wave. Results are presented in Fig .6. The calculated impulse at ground zero is 1.5 times larger than the experiment, as a consequence of the aforementioned “numerical jetting” on the axis. At other ground ranges, impulses from the computed waveforms agree very well with the measured impulses.

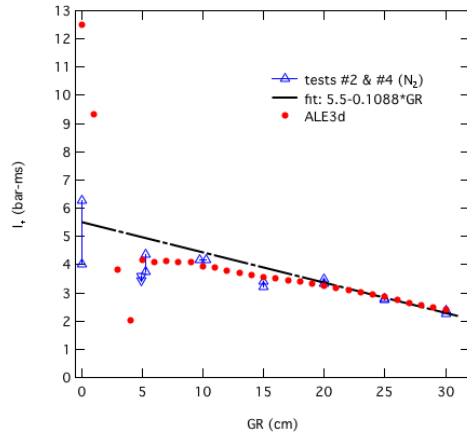


Figure 6. Positive phase impulse history versus ground range: calculation vs. experiments.

CONCLUSIONS

The reflected blast wave environment was measured in the 506-liter bomb calorimeter for 50-g spherical C-4 charges suspended 43 cm from a reflecting surface ($HOB = 11.7 \text{ cm/g}^{1/3}$). Peak reflected pressures ranged from 40 bars at ground zero to 20 bars at $GR = 30 \text{ cm}$. The corresponding positive phase impulses varied from 6 bar-ms down to values of $\sim 2 \text{ bar-ms}$ over the same ground ranges.

The reflected blast wave environment of the experiments was simulated with the ALE3D code.

The thermodynamic states were specified by the Cheetah code, which was used as an EOS subroutine. Neglecting ground zero (which suffered from numerical jetting effects), the computed waveforms were similar to the measured waveforms; the computed positive phase impulse agreed with the lower bound of the measured impulse at various ground ranges.

ACKNOWLEDGEMENTS

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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